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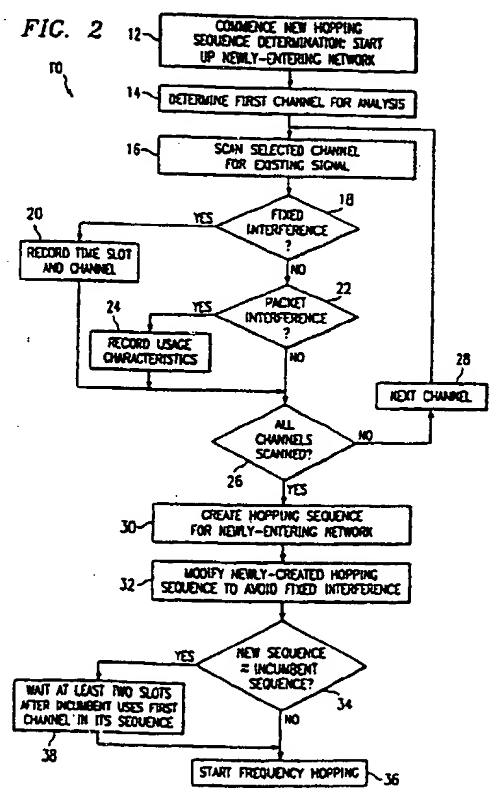
(54) System and method for wireless frequency hopping network

(57) A method (10) for determining a frequency hopping sequence for a newly-entering network. The method comprises the step of scanning (16) a plurality of frequency channels. For each of the plurality of frequency channels, the scanning step comprises detecting whether a signal (18,22) exists on the channel and recording information (20,24) corresponding to each channel on which a signal is detected. Finally, and responsive to the recorded information, the method forms (30) the frequency hopping sequence.

FIG. 2



newly-entering network) are labeled with an identifier P2. Further, the subscript for each packet identifies a time period encompassed by the duration of the packet. For example, during a time t_0, the first network transmits a packet $P1_0$ while also during time t_0 the second network transmits a packet $P2_0$. Further in this regard, in the prior art transmissions by the first network are asynchronous with respect to transmissions of the second network, both in start time and periodicity. Thus, time t_0 is only meant as a relative indication for the first packet from each network, and it is not intended to suggest that the packets from both networks begin and end at the same time.

[0006] With respect to all packets in Figure 1, the preceding demonstrates that each packet begins at a certain time, ends at a later time, and fills a certain frequency range (where the range is referred to as a channel). As a result and as described below, interference may occur if the area in Figure 1 defined by a packet overlaps or is within a certain distance of a packet from another wireless link. Indeed and as discussed below, such interference may occur in one of four different ways.

[0007] Time t_1 in Figure 1 illustrates a first type of packet interference, where it may be seen that the first network transmits a packet $P1_1$. After packet $P1_1$ commences but also during time t_1 the second network transmits a packet $P2_1$. The overlap of packets $P1_1$ and $P2_1$ is shown as a first collision C_1. Note that the horizontal alignment of packets $P1_1$ and $P2_1$ graphically indicates that in the example of collision C_1, both packets occupy the same frequency channel. Thus, collision C_1 represents an example where two different networks attempt to transmit packets during an overlapping time period and along the same channel.

[0008] Before proceeding with other types of packet collisions, an additional discussion is noteworthy with respect to a methodology which has been used to further reduce the likelihood and impact of packet collisions such as collision C_1. More particularly, this additional methodology is referred to in the art as listen-before-talk ("LBT"). In an LBT system, the system uses the hopping sequence described above, but prior to transmitting along a channel in the sequence the system monitors (or "listens") at the channel to determine if there is another packet already occupying that channel during the current time. Returning to packet $P1_1$ by way of example, if the second network employed LBT, then it would listen at the desired channel at which it intended to transmit $P2_1$ and would therefore detect the presence of packet $P1_1$. As a result, the second network would avoid collision C1 by not transmitting packet $P2_1$ at the desired frequency, but instead it would delay a random period and then proceed to the next designated channel of its hopping sequence. Next, the second network would listen at that next designated channel to again determine if that channel was occupied by a packet from another network, and if no packet was detected then the second network would transmit its packet; however, if this next designated channel also was occupied, then the second network would continue to examine additional channels in this same manner until a channel was detected without being occupied by a packet from another network, at which time the second network would transmit its packet along the now unoccupied channel. Given this process, however, note that a delay arises in LBT systems, where the amount of delay depends on the number of times that the LBT network is forced to listen, detect, and advance from an occupied channel, and then delay an additional random period to listen, detect, and transmit along an unoccupied channel.

[0009] While LBT as shown above reduces the possibility of collisions, it also has drawbacks. For example, LBT delays transmission by the network which was prepared to transmit along a channel but was prevented from doing so due to an already-transmitted packet in the desired channel. As another example, it adds an element of delay to each packet due to its listening aspect. Also, all the devices in an environment must utilize LBT to gain the most benefit (fairness) of the scheme. As still another example, some protocols (e.g., Bluetooth) utilized in the unlicensed bands do not support LBT, while such protocols may nonetheless provide other beneficial aspects and, thus, the choice to use such a protocol is a tradeoff in that other aspects are obtained without the availability of LBT.

[0010] Time t_2 in Figure 1 illustrates a second type of packet interference in connection with a collision C_2 occurring between a first network packet $P1_2$ and a second network packet $P2_2$. For collision C_2, the incumbent first network transmits packet $P1_2$ during a period including time t_2 and at a first channel, and thereafter the second network transmits packet $P2_2$ also during a period including time t_2 (i.e., the periods of the packets overlap). Packet $P2_2$ is transmitted at a second channel which, while different than the channel of packet $P1_2$, it is immediately adjacent the channel occupied by packet $P1_2$. Further in this regard, it is known in the art that while packets occupy a certain channel as shown by the vertical displacement of a packet in Figure 1, there is an additional tendency for a packet to provide slight interference or "splatter" into adjacent frequency channels. As a result of this effect, even though packets $P1_2$ and $P2_2$ occupy different channels, they are still in adjacent channels and, thus, they are close enough to one another in frequency such that the splatter effect causes a collision between the packets. Indeed, in some networks the filters used are relatively inexpensive and, as a result, the concept illustrated with packets $P1_2$ and $P2_2$ may also apply to next-adjacent channels, that is, to the channels that are one more channel away from the channels adjacent to the channel in which a packet is transmitted. Thus, collision C_2 represents an example where two different networks attempt to transmit packets during an overlapping time period and along adja-

achieve the above goals while complying the with the above-described FCC requirements. The preferred embodiments described below avoid these requirements by not requiring the newly entering network to have knowledge of or cooperation with the incumbent network.

[0017] In the preferred embodiment, there is a method for determining a frequency hopping sequence for a newly-entering network. The method comprises the step of scanning a plurality of frequency channels. For each of the plurality of frequency channels, the scanning step comprises detecting whether a signal exists on the channel and recording information corresponding to each channel on which a signal is detected. Finally, and responsive to the recorded information, the method forms the frequency hopping sequence. Other circuits, systems, and methods are also disclosed and claimed.

[0018] Specific embodiments of the invention will now be described, by way of example only, and with reference to the accompanying drawings, in which:

Figure 1 illustrates various packets transmitted by a first and second network and demonstrates potential collisions between such packets as well as interference from a band of fixed interference;
Figure 2 illustrates a flow chart of the preferred embodiment as implemented in a method performed by a network transceiver; and
Figure 3 illustrates a block diagram of a network transceiver operable to perform the method shown in Figure 2.

[0019] Figure 1 was described in the introductory description of this document and the reader is assumed familiar with that description.

[0020] Figure 2 illustrates a flow chart of a method 10 according to the preferred embodiment and for operating a wireless network so as to reduce the drawbacks described above in connection with the prior art. By way of introduction to this preferred embodiment, the following discussion demonstrates that by the conclusion of method 10 an improved hopping sequence is generated for a wireless network. The hopping sequence is improved in two respects. First, the hopping sequence is such that packets may be communicated according to it and results in a reduced amount of packet collisions as compared to a prior art non-LBT wireless frequency hopping system. Second, the hopping sequence is such that packets may be communicated according to it and results in a reduced incidence of conflict with fixed interference as compared to a prior art non-LBT wireless frequency hopping system. These benefits are illustrated in greater detail after the following detailed discussion of method 10. Finally, it should be noted that method 10 may be implemented in connection with various types of wireless networks as may be ascertained by one skilled in the art and as further addressed later. Additionally, such a person also may determine various different circuits and software implementations given the selected network, as is also explored later by way of example.

[0021] Method 10 begins with a step 12 where the wireless network begins the determination of a new hopping sequence to be used for intercommunications on the network (i.e., by all transmitters, receivers, and transceivers in the network). To facilitate the remaining discussion, the network which will use this new hopping sequence is referred to as the newly-entering network. This terminology is chosen because the newly-entering network's communications are new with respect to any one or more incumbent networks that already may be communicating along the frequency band to be used by the newly-entering network. In the preferred embodiment, step 12 occurs at network start-up, such as when a first transceiver of the newly-entering network is turned on or is otherwise initialized. Next, method 10 continues to step 14.

[0022] In step 14, a first frequency channel is selected for analysis. More particularly and as will become apparent given the remaining discussion of method 10, in the preferred embodiment each channel along which the newly-entering network may transmit is individually analyzed by method 10 at least once. Accordingly, step 14 operates so that a first one of these channels is selected to be analyzed. This selection may be implemented in various fashions, such as by assigning a unique and ascending number to each increasing frequency channel which is available to the newly-entering network, and then step 14 may operate by initializing a counter to the first assigned number. Other implementations may be ascertained by one skilled in the art. In any event, once a first channel is selected for analysis, method 10 continues to step 16.

[0023] In step 16, the channel selected by step 14 is scanned to determine if there is an existing signal in that channel. In the preferred embodiment, the known receive signal strength indicator ("RSSI") is used as the scan technique. Note that an existing signal may be detected in the scanned channel due to various events as illustrated earlier in connection with Figure 1. For example, an existing signal will be detected in step 16 if there is fixed interference in the scanned channel (or in a channel one or two adjacent channel locations from the scanned channel). As another example, an existing signal will be detected in step 16 if another network has transmitted a packet that, during the duration of the scan, is either in the scanned channel or in a channel that is adjacent the scanned channel. Each of these possibilities is responded to by one or more additional steps, as discussed below. Following the scan of step 16, method 10 continues to step 18.

[0024] Step 18 directs the flow of method 10 if the interference, if any, detected in step 16 is fixed interference. The determination of whether a particular detected interference is fixed interference (as opposed to packet interference) may be made in various fash-

For example, recall that earlier in connection with step 14 an approach was given where a counter was set to correspond to a first channel to be scanned. If this approach is selected, then step 28 may be implemented by incrementing this counter. In any event, once the network is properly prepared to evaluate another channel, method 10 returns from step 28 to step 16 and the above-described options are taken with respect to the next channel.

[0030] At some point given the return flow of method 10 described above, step 26 will determine that all channels available for transmission by the newly-entering network have been scanned; as noted above, at this point method 10 reaches step 30. Step 30 determines a hopping sequence for the newly-entering network given the information recorded by any previous occurrences of steps 20 and step 24. In other words, once step 30 is reached, if either or both of fixed or packet interference has been detected, then information has been stored regarding such interference and step 30 derives a favorable hopping sequence from that information. More particularly, given the detected information, step 30 generates a hopping sequence that will thereafter be used for transmission by the newly-entering network. This derived hopping sequence seeks to minimize the possibility that packets sent by the newly-entering network, and according to that hopping sequence, will incur interference given the already-existing interference as detected by earlier occurrences of step 16. In the preferred embodiment, the step 30 derivation of the hopping sequence is based, first, on determining, if possible, the hopping sequence of the incumbent network from previous information recorded in occurrences of step 24, and also in view of any recorded fixed interference recorded in occurrences of step 20. Thereafter, and as discussed later, the hopping sequence for the newly-entering network is derived. First, therefore, the preferred methods for determining the incumbent network's hopping sequence are described below. Second, the preferred methods for determining the newly-entering network's hopping sequence in view of the incumbent network's hopping sequence are also described below.

[0031] A first approach for determining the incumbent network hopping sequence is straightforward if an earlier occurrence of step 24 was able, as described above, to properly recover the header information from a detected incumbent network packet. In other words, recall that the header information includes an indication of the hopping sequence of the incumbent network which transmitted the packet. Thus, if such a header was properly decoded, then step 30 merely derives the incumbent network's hopping sequence from the indication in the packet header.

[0032] A second approach for determining the incumbent network's hopping sequence is achieved by extending the duration of step 16 to be large relative to the time that the incumbent network is expected to maintain a transmission along each of its available channels. For example, if the incumbent network is a Bluetooth network, then it is known that it will hop 1600 times a second, where for each hop only one packet is transmitted followed by another hop and packet transmission, and so forth. In addition, a Bluetooth network may hop among 83 different channels. Thus, where the incumbent network is a Bluetooth network, then the duration of step 16 may be set, by way of example, to one second. Given this duration, note that on average, for this one second duration which will therefore include 1600 hops to one of 83 different channels, then each different channel should be used approximately 19.27 times (i.e., 1600/83=19.27). As a result, during the one second scan duration in a given channel, approximately 19.27 packet detections should occur for that channel, and these detections are stored as the above-mentioned usage characteristics. Still further, this one second duration is then repeated for each different scanned channel, further enhancing the map to demonstrate approximately 19.27 detected packets for each channel scanned, along with the time intervals within the one second duration for different channel usages. Still further in the Bluetooth protocol, the hopping sequence repeats after 1600 hops; accordingly, given the mapped information described above, an accurate determination of the incumbent network's hopping sequence may be derived.

[0033] A third approach for determining the incumbent network's hopping sequence is achieved by shortening the duration of step 16 to be short relative to the time that the incumbent network is expected to maintain a transmission along one channel. More particularly, in this third approach each channel is scanned for a short enough duration so that all possibly used channels are scanned in a time period that is no greater than the time period that the incumbent network will continue to transmit along a single channel. Again using the example of an incumbent Bluetooth network, recall that it transmits successive packets along a maximum of 83 different channels. Accordingly, for the third approach the scan duration is equal to (or no greater than) 1/83 times the duration of a packet. By scanning in this manner, for 83 successively scanned channels, where each channel is scanned for only 1/83 of a packet duration, and assuming only a single Bluetooth incumbent network is transmitting, then only one channel during the scan should be found to be occupied by a packet (although adjacent channels may detect interference from the packet splatter). In this approach, note that step 26 of method 10 is modified so that the channels are scanned numerous times rather than just scanning all available channels once, so that eventually method 10 will detect usage in each of the available channels. Once more using the Bluetooth incumbent network by way of example, it is probable that after 1600 scans of each of the 83 channels (where each channel is scanned for 1/83 of the packet duration), then the entire incumbent network

be detailed in connection with the operation of transceiver 40 relative to method 10. Lastly, the three primary blocks of transceiver 10, as well as the signals shown between those blocks, are discussed below in an order that parallels the steps of method 10 discussed earlier.

[0039] To commence method 10, MAC controller 46 asserts the Scan Command signal to physical engine 44. In response and to accomplish steps 16 through 24, physical engine 44 selects a channel and indicates the selected channel to radio 42 by the TX/RX Frequency signal. In response, radio 42 adjusts (e.g., its oscillator) to examine the signal at the indicated frequency and, recall in the preferred embodiment, an RSSI measurement is made at this frequency. Further in this regard, recall that it is discussed above that the preferred embodiment evaluates sub-channels within each selected scanned channel to determine if detected interference, if any, is either fixed interference or packet interference. Accordingly, physical engine 44 may indicate each such sub-channel to radio 42 via the Subchannel Scan signal or may indicate by that signal that sub-channels should be evaluated for the channel specified by the TX/RX Frequency signal; alternatively, radio 42 may be set up to evaluate a certain number of sub-channels (e.g., ten) for each channel indication it receives from physical engine 44. In any event, as radio 42 sweeps across sub-channels and determines corresponding RSSI measurements, it returns each measurement via the RSSI signal shown from radio 42 to physical engine 44. In response to the RSSI measurements, physical engine 44 makes the determinations of step 18 (i.e., whether interference is fixed) and step 22 (i.e., whether interference is from a packet), and potentially responds by taking the actions of steps 20 and 24, respectively. In addition, if RSSI is zero or negligible for a given scanned channel, then the preferred embodiment determines that there is no interference on that channel. In any event, once a channel is evaluated, physical engine 44 achieves step 28 by adjusting the TX/RX Frequency signal to the next channel (or sub-channel within the next channel) to be scanned, and the process repeats for all channels. Finally, once all channels are selected, the results of all detected interference are reported by physical engine 44 to MAC controller 46 via the Scan Results signal.

[0040] Once MAC controller 46 receives the Scan Results signal, it performs steps 30 and 32 directed to creating and modifying a new hopping sequence for the newly-entering network. Further, once this new hopping sequence is finalized, then MAC controller 46 communicates it to physical engine 44 via the Hop Sequence signal, and MAC controller 46 then instructs MAC controller 46 to actually begin hopping (i.e., transmitting per the new hop sequence) by asserting the Hop Control signal. This latter aspect, therefore, may be asserted to accommodate the delay aspect of step 38 if applicable.

[0041] From the above, it may be appreciated that the preferred embodiments provide various alternatives whereby a newly-entering network first scans the frequency channels along which it may transmit and in response to existing signals on those channels a hopping sequence is derived for the newly-entering network. The hopping sequence for the newly-entering network provides numerous advantages over the prior art. For example, packets transmitted according to the newly-entering network's derived hopping sequence are considerably less like to incur interference as opposed to a non-LBT prior art wireless network. Further in this regard, therefore, the preferred embodiments may be used with Bluetooth or other non-LBT protocols, thereby gaining access to the features of those protocols, while still having a reduced incidence of packet interference even without the LBT functionality. Indeed, this benefit is particularly useful given that Bluetooth may well become a very prevalent protocol and, for this reason, the preferred embodiment specifically contemplates a Bluetooth implementation. As another example, the preferred method does not require a delay associated with each individual packet transmission as does an LBT architecture. As still another example, recall that the FCC imposes a regulation on wireless networks in that they are not permitted to explicitly coordinate with one another, and the preferred embodiment satisfies this regulation while still achieving a reduced incidence of packet interference. As still another example, while the preferred embodiment has been discussed primarily in connection with the Bluetooth protocol, such discussion is by way of example and, thus, the above teachings may be applied to other systems as well (e.g., IEEE 802.11) and combination of several Bluetooth and 802.11 frequency hopping devices. Still further, the preferred embodiment may be used in numerous different wireless band systems (e.g., the ISM band, and others). Consequently, while the present embodiments have been described in detail, the preceding further demonstrates that various substitutions, modifications or alterations could be made to the descriptions set forth above without departing from the inventive scope which is defined by the following claims.

[0042] An optional embodiment comprises a computing device such as a general purpose microprocessor or digital signal processor, configured to operate a transceiver in accordance with the flowchart illustrated in Figure 2. The programmable logic device is configured by means of a computer program to perform the steps of the flowchart of Figure 2, in cooperation with the operational elements of the transceiver.

[0043] The computer program may be carried or stored in any suitable carrier medium, such as volatile or non-volatile solid state memory, resident in the transceiver or associated circuitry. Additionally, the computer program may be carried on a magnetic disc or tape, or over a telecommunications medium such as an optical frequency or radio frequency carrier signal, for delivery

after the waiting step, transmitting a packet with the newly-entering network according to the hopping sequence for the newly-entering network.

14. The method of claim 1:
wherein the detecting step detects packet signals in response to packets communicated along the plurality of frequency channels by an incumbent network having an incumbent network hopping sequence;
wherein the detecting step detects signals in response to fixed interference along at least one of the plurality of frequency channels; and
wherein the step of forming the frequency hopping sequence for the newly-entering network comprises:

forming a first hopping sequence equal to the incumbent network hopping sequence; and
forming the frequency hopping sequence for the newly-entering network by modifying the first hopping sequence to not include any one of the plurality of channels along which fixed interference is detected.

15. The method of claim 14, wherein the modifying step comprises selecting an alternative channel from a rotation of channels such that the selected alternative channel is used in the frequency hopping sequence for the newly-entering network in place of one of the plurality of channels along which fixed interference is detected.

16. The method of claim 15, wherein the rotation of channels comprise a plurality of interference-free channels in which the detecting step has not detected a signal existing on each of the interference-free channels.

17. The method of any one of claims 1 to 15:
wherein the scanning step is operable to identify packet signals in response to a hopping sequence of an incumbent network;
wherein the hopping sequence of the incumbent network consists of an integer number N of different channels along which the incumbent network may transmit packets;
wherein the step of scanning a plurality of frequency channels comprises scanning each of the plurality of frequency channels multiple times; and
wherein for each of the multiple times each of the plurality of frequency channels is scanned for a period no greater than a ratio of one over the integer N.

18. The method of any one of claims 1-15:
wherein the scanning step is operable to identify packet signals in response to a hopping sequence of an incumbent network;
wherein the hopping sequence of the incumbent network consists of an integer number M of sequence channels over which the incumbent network is operable to transmit packets before repeating the hopping sequence of the incumbent network; and
wherein the step of scanning a plurality of frequency channels comprises scanning each of the plurality of frequency channels for a period at least equal to a time required by the incumbent network to transmit packets along the integer number M of sequence channels.

19. A computer program for configuring a computing device to implement and/or control a communications device to carry out the steps of any one of claims 1 to 18.

20. A computer program carrier medium carrying a computer program according to claim 19.

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FIG. 2

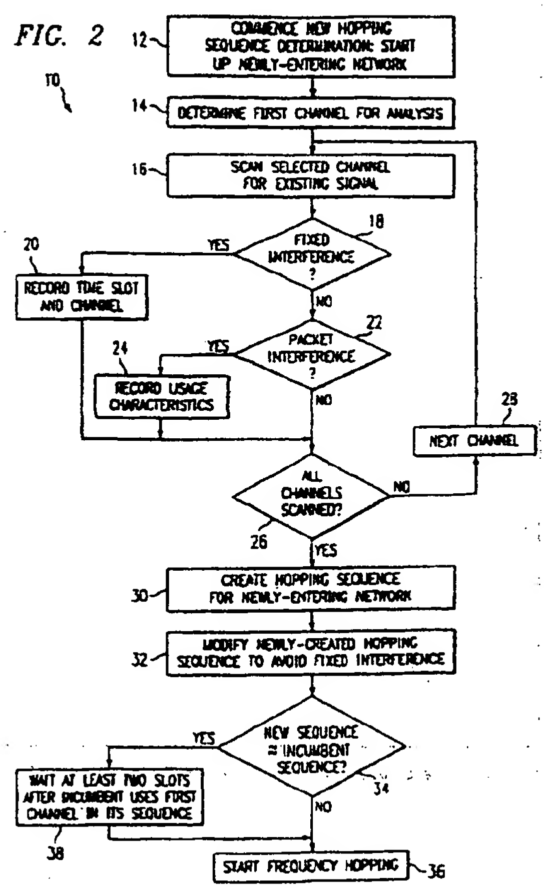

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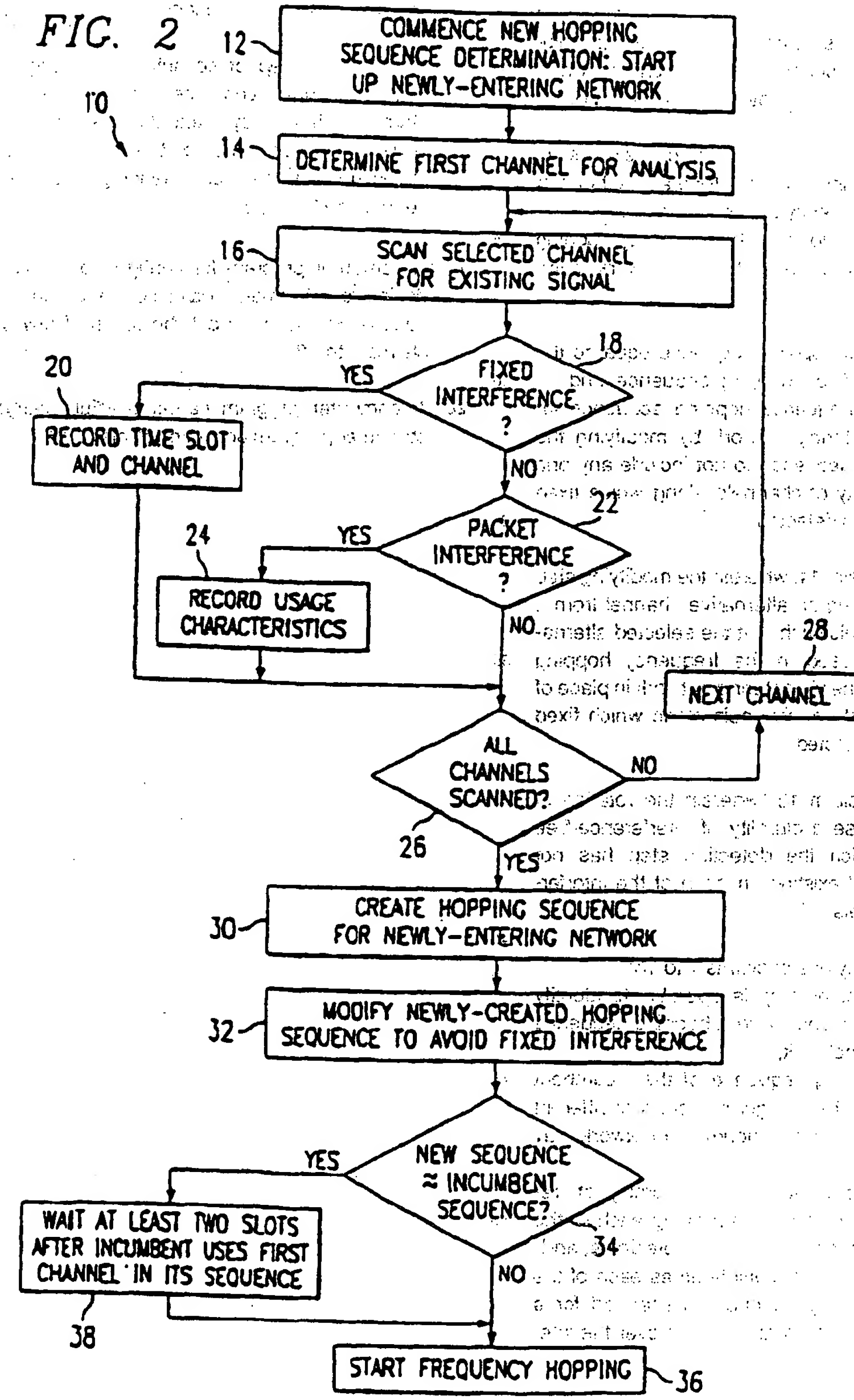
FIG. 2


10
12
COMMENCE NEW HOPPING SEQUENCE DETERMINATION: START UP NEWLY-ENTERING NETWORK
14
DETERMINE FIRST CHANNEL FOR ANALYSIS
16
SCAN SELECTED CHANNEL FOR EXISTING SIGNAL
18
FIXED INTERFERENCE ?
YES
NO
20
RECORD TIME SLOT AND CHANNEL
22
PACKET INTERFERENCE ?
YES
NO
24
RECORD USAGE CHARACTERISTICS
28
NEXT CHANNEL
ALL CHANNELS SCANNED?
NO
YES
26
30
CREATE HOPPING SEQUENCE FOR NEWLY-ENTERING NETWORK
32
MODIFY NEWLY-CREATED HOPPING SEQUENCE TO AVOID FIXED INTERFERENCE
NEW SEQUENCE ≈ INCUMBENT SEQUENCE?
34
YES
NO
WAIT AT LEAST TWO SLOTS AFTER INCUMBENT USES FIRST CHANNEL IN ITS SEQUENCE
38
START FREQUENCY HOPPING
36

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 00 30 2259

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 5528622	A	18-06-1996	NONE		
US 4716573	A	29-12-1987	SE 445698	B	07-07-1986
			CA 1252151	A1	04-04-1989
			DE 3565620	D1	17-11-1988
			EP 0182762	A1	28-05-1986
			SE 8405818	A	20-05-1986
US 5809059	A	15-09-1998	CN 1183682	A	03-06-1998

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